EFFECT OF FINE AGGREGATE TYPE ON CLSM PROPERTIES

L. K. CROUCH
Ph.D., P.E., Professor of Civil Engineering Tennessee Technological University
Cookeville, Tennessee, USA

V. JAMES DOTSON, JR.
E.I. Graduate Research Assistant Tennessee Technological University
Cookeville, Tennessee, USA

LARRY CLOUSE
Account Executive, Master Builders Technologies
Knoxville, Tennessee, USA

STEVE M. HALL
P.E., Assistant Engineering Director, Tennessee Department of Transportation Division of Materials & Tests
Nashville, Tennessee, USA

ABSTRACT

A high-flow, rapid-set, non-excavatable controlled low-strength material (flowable fill) was developed for applications where time was critical. The mixture was required to be ready for load application in six hours regardless of subgrade moisture conditions and use materials commonly available at ready mix facilities. Further, the mixture, called ZOOM, must be able to tolerate a wide variety of Tennessee fine aggregates types including Ohio River sand, manufactured limestone sand, limestone screenings, and crushed sandstone.

An initial ZOOM mixture was produced using Ohio River sand. Subsequently, the mixture proportions were adjusted to produce the desired plastic and hardened properties with other Tennessee fine aggregates. Laboratory work and three successful field demonstrations indicated that fine aggregate properties such as gradation and angularity dictate mixture proportions required to achieve flow, air content, and bleeding characteristics and therefore indirectly influence time of suitability for load application and compressive strength development.

Keywords: fine aggregate, angularity, particle shape, gradation, CLSM, air content, flow consistency, ball drop apparatus, compressive strength

Introduction

The Tennessee Department of Transportation Division of Materials & Tests saw a need for a rapid set, non-excavatable Controlled Low-strength Material (CLSM) for applications where time was a critical factor such as rapid subgrade repairs. CLSM initial set can occur in two ways: dewatering and chemical reactions. The research team decided that the CLSM should initially harden due to chemical reactions rather than by bleeding (dewatering) in case of unfavorable placement conditions. The new CLSM needed to set and gain compressive strength rapidly yet have a very fluid consistency while plastic. The new CLSM mixture was named ZOOM to reflect the rapid set and strength gain.

Research Objectives

Tennessee Technological University (TTU) researchers established the criteria shown in Table 1 for the ZOOM mixture.

ZOOM! Proportions with Ohio River Sand Fine Aggregate (Control Aggregate)

The initial ZOOM mixture was proportioned by trial batches in the laboratory at TTU with Ohio River Sand fine aggregate. The Ohio River Sand used is the common fine aggregate for Portland cement concrete in West and Middle Tennessee. The initial ZOOM mixture proportions are shown in Table 2 and the initial plastic properties are shown in Table 3.

Other Fine Aggregates

Three additional fine aggregates were selected to represent the fine aggregate types commonly available across the state of Tennessee. Manufactured Limestone Sand is commonly used in East Tennessee. In addition, some concrete producers on the Cumberland Plateau Region use crushed sandstone fine aggregate. Limestone screenings were included due their abundance in Middle and East Tennessee. The use of screenings would help address an industry-wide problem as well as reduce ZOOM cost if the screenings proved to be a viable aggregate. Fine aggregate gradations, determined as per AASHTO T 11-96 (1) and AASHTO T 27-99 (2) are shown in Figure 1. Uncompacted void values, determined in accordance with AASHTO T 304-96 (3), are shown in Figure 2. Fine aggregate specific gravities and absorptions, determined in accordance with AASHTO T84-00 (4), are shown in Table 4.

Effects of Substitution of Other Fine Aggregates

Table 5 shows a comparison of the critical fine aggregate properties for ZOOM CLSM. Table 6 shows the plastic properties of the ZOOM CLSM mixtures with other fine aggregates substituted for the Ohio River sand control aggregate. The properties of the other fine aggregates selected are compared with properties of the control aggregate. The following paragraphs describe the effects of the properties of other fine aggregates on properties of ZOOM CLSM.

Manufactured Limestone Sand

Previous unpublished research at TTU indicated that a more angular aggregate (as indicated by AASHTO T 304-96 Method B U_m = 45.43) might entrain more air than the control aggregate (U_m = 42.97). Air content increased from 25.7 percent for the control aggregate to 31.1 percent for manufactured limestone sand aggregate ZOOM. Flow increased from 8.5 inches to 9.75 inches due to the increased air content. Bleeding was reduced by a denser gradation and higher fines content (C_u = 5.93, 5.1%) compared to the control aggregate (C_u = 2.10, 0.4%).

Limestone Screenings

Two conflicting factors effected air content of the ZOOM limestone screenings mixture. As previously stated, more angular aggregates increase air entrainment. Limestone screenings are much more angular than the control aggregate as indicated by both AASHTO T 304 Methods A and B (U_s = 48.61 and U_m = 52.38 for limestone screenings vs. U_s = 39.92 and U_m = 42.97 for the control aggregate). However, the dominant factor was fines content (15% vs. 0.4%) reducing the air content from 25.7 percent to 16.6 percent.

Several factors reduced the flow of the limestone screenings ZOOM mixture to zero. First, the particle shape (U_s = 48.61 and U_m = 52.38) of the limestone screenings approached a flat and elongate condition. ACI 221-96 (5) sited the work of Gray and Bell (6) who recommended a maximum U_m of 53 percent to avoid flat and elongate conditions. Second, the high fines content (15% vs. 0.4%) was the most important factor in reducing flow. Third, the denser gradation (C_u = 29.33 vs. C_u = 2.10 for the control aggregate) made obtaining adequate flow more difficult. Finally, and perhaps least importantly, a higher FM (3.25) indicates a much coarser gradation than ORS (FM = 2.64). Coarser particles are harder to mobilize. Bleeding was not a problem due to the high fines content and denser gradation.

Crushed Sandstone

Air content rose from 25.7 to 30.4 percent due to more angular aggregate particles (U_m = 47.27 for crushed sandstone vs. U_m = 42.97 for the control aggregate). Flow dropped from 8.5 inches to 6.5 inches. The previously mentioned angularity of the crushed sandstone particles compared to the control aggregate was certainly a factor. In addition, the crushed sandstone had a much finer gradation as indicated by the comparison of fineness modulii (FM = 2.11 for crushed sandstone compared to FM = 2.64 for the control aggregate). The finer aggregate required more paste to coat and mobilize the particles.

Bleeding did not occur with the initial substitution of crushed sandstone for the control aggregate. However, flow concerns required more paste to mobilize aggregate. Unfortunately the gradation (U_r = 43.67) is much more open than the control aggregate gradation (U_r = 40.19), this would lead to bleeding problems after mixture proportion adjustment. Further, plastic cohesion problems resulted from 58.9 percent of aggregate passing the No. 30 sieve and being retained on the No. 50 sieve.

Mixture Proportion Adjustments for Other Fine Aggregates

Adjustments were not required for the limestone manufactured sand ZOOM CLSM. The adjustments and revised proportions for the limestone screenings and crushed sandstone mixtures are shown in Table 7. Plastic properties for the adjusted mixture proportion limestone screenings and crushed sandstone mixtures are shown in Table 8. The research team was not able to satisfy both flow and bleeding requirements for the crushed sandstone ZOOM CLSM. The research team was able to raise the flow to 7.25 inches without bleeding by increasing the high-range water reducer.

Field Demonstration Results and Analysis

Field demonstrations of ZOOM CLSM were held in Nashville, Knoxville, and Algood, Tennessee using fine aggregate commonly used for PCC in the area. Each field demonstration consisted of one or more trench (approximately 3 feet wide, 3.5 feet deep and 9 feet long) placements using the local fine aggregate(s). Testing of the ZOOM CLSM was conducted at each location and currently available information was distributed to government and industry personnel present.

Figures 3 and 4 show comparisons of compressive strength development for field demonstrations and laboratory ZOOM CLSM mixtures. Figures 5, 6, and 7 show comparison of flow, air content and time to pass the ball drop test, respectively. Compressive strength specimens were not fabricated at Irving Materials Inc. (IMI) Nashville. Ball drop test data is not available for the limestone screenings ZOOM CLSM due to excessive water in the trench precluding ball drop testing.

ZOOM CLSM met compressive strength development and time of set performance criteria at every field demonstration. However, ZOOM CLSM made with the Ohio River sand control aggregate failed to achieve the desired flow in the lab and for Nashville Number 1 Trench. In each case, the flow was greater than 8 inches but less than 8.75 inches. Limestone manufactured sand ZOOM CLSM mixtures failed to fall within the desired air content range in the lab and for Knoxville Number 1 Trench. Neither case adversely affected the other mixture properties enough to cause a failure in compressive strength, set time, or flow.

The effect of fine aggregate type on time of set and compressive strength appeared to be indirect. ZOOM temperature, air content, PC content, and accelerator dosage appeared to have the greatest effect on set time and compressive strength development. Different types of fine aggregates required different PC and air contents to achieve the desired flow characteristics. The research team suspected that the more rapid compressive strength development of limestone screenings was partially due to acceleration of hydration by the limestone fines, however, the limestone screenings mixture had the highest PC content as well and insufficient data was available in this study to make a determination.

Conclusion

A rapid-set non-excavatable CLSM for applications where time was a critical factor can be produced with a wide variety of Tennessee fine aggregates types. Fine aggregate properties such as gradation and angularity dictate mixture proportions required to achieve flow, air content, and bleeding characteristics and therefore indirectly influence time of set and compressive strength development.

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Disclaimer

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Table 1. ZOOM CLSM Mixture Criteria

Parameter	Requirement
Application	Rapid-set structural fill or working platform
ASTM D 6024 Ball Drop Test (7)	Pass in 6 hours or less regardless of subgrade moisture
Bleeding	Little or no bleeding
Shrinkage	Little or no shrinkage
ASTM D 6103 Flow (8)	8.75-inches minimum
ASTM D 6023 Air Content (9)	Prefer 20 to 30 percent
ASTM D 4832 compressive strength (10)*	30-psi minimum at 24-hours
Excavatability	No requirement
Aggregates	Producible with a wide variety of Tennessee aggregates

* -revised as recommended by Sauter and Crouch (11)

Table 2. Initial ZOOM CLSM Plastic Properties with Ohio River Sand Control Aggregate

Property	Ohio River Sand (Control Aggregate)	Requirement
Flow (inches)	8.5	8.75 minimum
Bleed Time (min)	4.5	Little or no bleeding
Shrinkage	Minimal	Little or no shrinkage
Air Content (%)	25.7	20 to 30 preferred
Unit Weight (pcf)	104.6	No requirement
Meet Requirements / Problems	No Best combination of flow and bleeding achievable	

Table 3. Initial ZOOM CLSM Mixture Proportions Developed from Trial Batches with Ohio River Sand Control Aggregate

Component	Amount
Type 1 Portland cement	300 lbs/CY
Water	317 lbs/CY
Ohio River Sand (SSD)	2425 lbs/CY
Air-entraining agent	70 oz/CY
High-range water reducer	30 oz/CY
Accelerator	225 oz/CY

Table 4. CLSM Aggregate Specific Gravities and Absorptions

Aggregate	Apparent SG	Bulk SG (dry)	Bulk SG (SSD)	Absorption (%)
Ohio River Sand (Control)	2.645	2.583	2.607	0.93
Manufactured Limestone Sand	2.676	2.588	2.621	1.27
Limestone Screenings	2.760	2.676	2.708	1.11
Crushed Sandstone	2.658	2.611	2.628	0.65

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Table 5. ZOOM CLSM Aggregate Property Summary

Aggregate	% Passing #200	FM	C_u	T 304 U_s	T 304 U_m	T 304 U_r
Ohio River Sand (Control)	0.4	2.64	2.10	39.92	42.97	40.19
Manufactured Limestone Sand	5.1	3.10	5.93	41.41	45.43	39.22
Limestone Screenings	15.0	3.25	29.33	48.61	52.38	40.52
Crushed Sandstone	2.6	2.11	2.56	42.90	47.27	43.67

Table 6. ZOOM CLSM Plastic Properties for other Aggregates using the Control Aggregate Mixture Proportions

Property	Manufactured Limestone Sand	Limestone Screenings	Crushed Sandstone
Flow (inches)	9.75	Shear (No Flow)	6.5
Bleed Time (min)	No Bleeding	No Bleeding	No Bleeding
Shrinkage	No Shrinkage	No Shrinkage	No Shrinkage
Air Content (%)	31.1	16.6	30.4
Unit Weight (pcf)	102.1	121.76	99.2
Problems	None	Flow & Air	Flow
Possible Solutions	None Required	Increase air volume & paste fluidity	Make paste more fluid

Table 7. ZOOM CLSM Adjusted Mixture Proportions for Non-control Aggregates

Component	Limestone Screenings	Crushed Sandstone
Type 1 Portland cement	350 lbs/CY Control + 50 lbs/CY	300 lbs/CY
Water	375 lbs/CY Control + 58 lbs/CY	317 lbs/CY
Fine Aggregate (SSD)	2335 lbs/CY	2460 lbs/CY
Air-entraining agent	105 oz/CY Control + 35 oz/CY	70 oz/CY
High-range water reducer	45 oz/CY Control + 15 oz/CY	91 oz/CY Control + 61 oz/CY
Accelerator	225 oz/CY	225 oz/CY

Table 8. ZOOM CLSM Plastic Properties for other Aggregates using the Adjusted Mixture Proportions

Property	Limestone Screenings	Crushed Sandstone	Requirement
Flow (inches)	9.50	7.25	8.75 minimum
Bleed Time (min)	No Bleeding	No Bleeding	Little or no bleeding
Shrinkage	No Shrinkage	No Shrinkage	Little or no shrinkage
Air Content (%)	22.0	26.4	20 to 30 preferred
Unit Weight (pcf)	110.6	104.8	No requirement
Meet Requirements?	Yes	No, low flow	

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Figure 1. CLSM Fine Aggregate Gradation Comparison

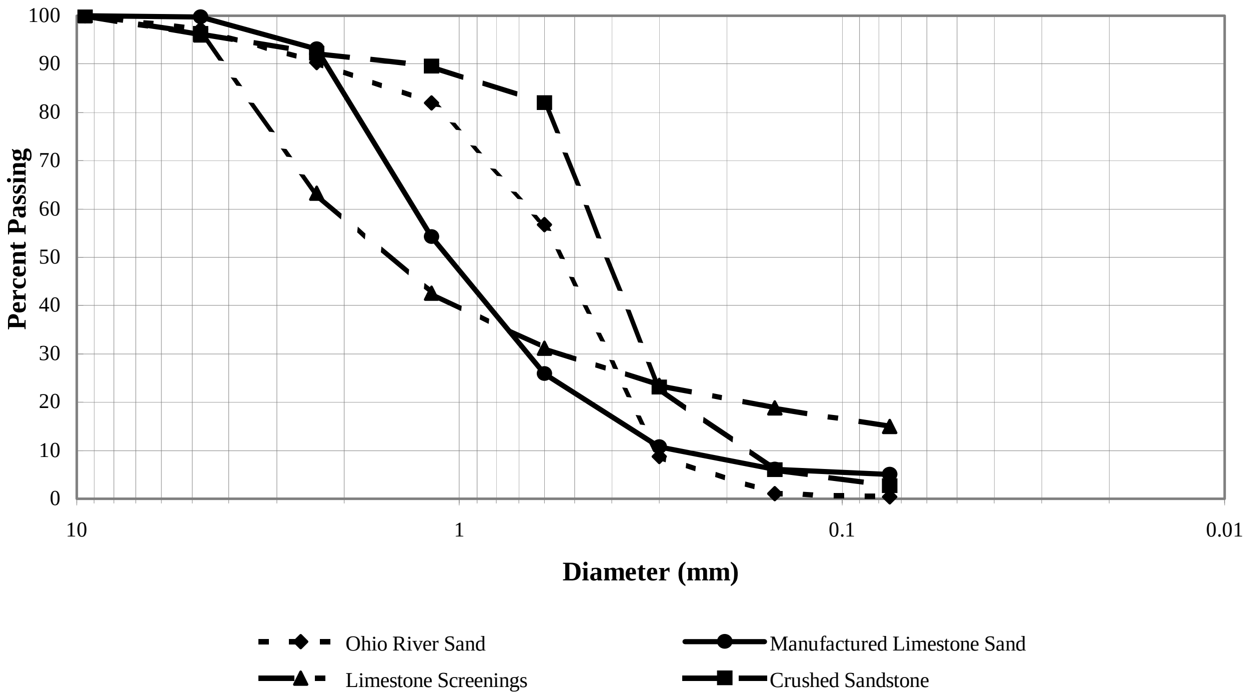

Figure 2. Comparison of CLSM Fine Aggregate Angularity Values (AASHTO T 304)

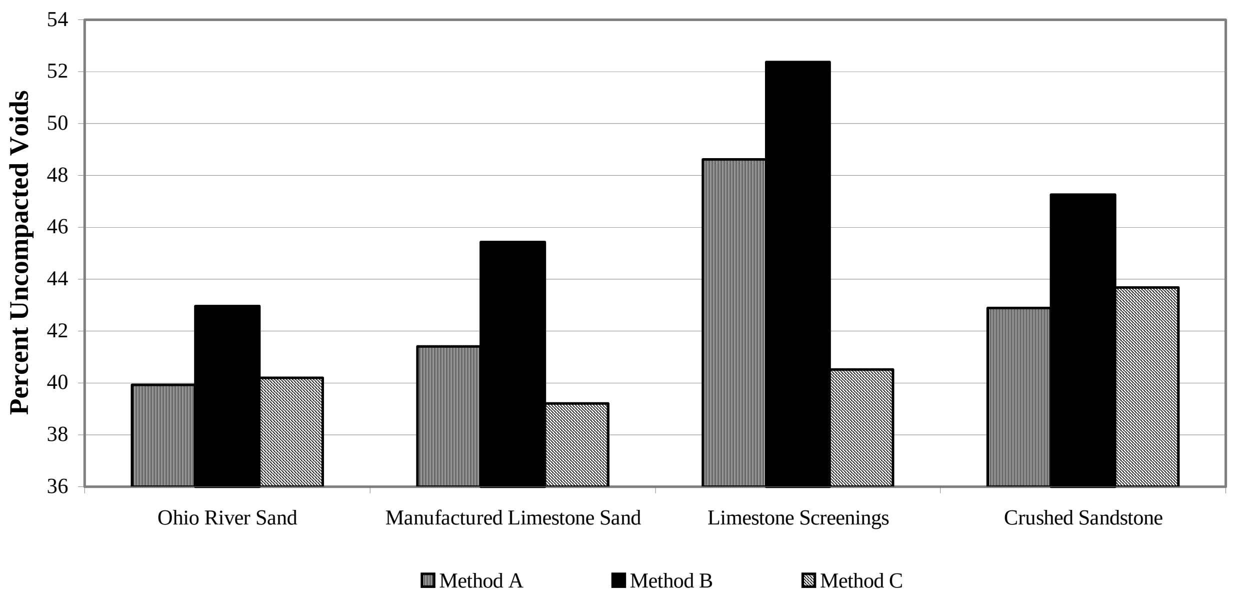

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Figure 3. Comparison of Lab and Field Compressive Strength Development for LS Screenings and LS Manufactured Sand Mixtures

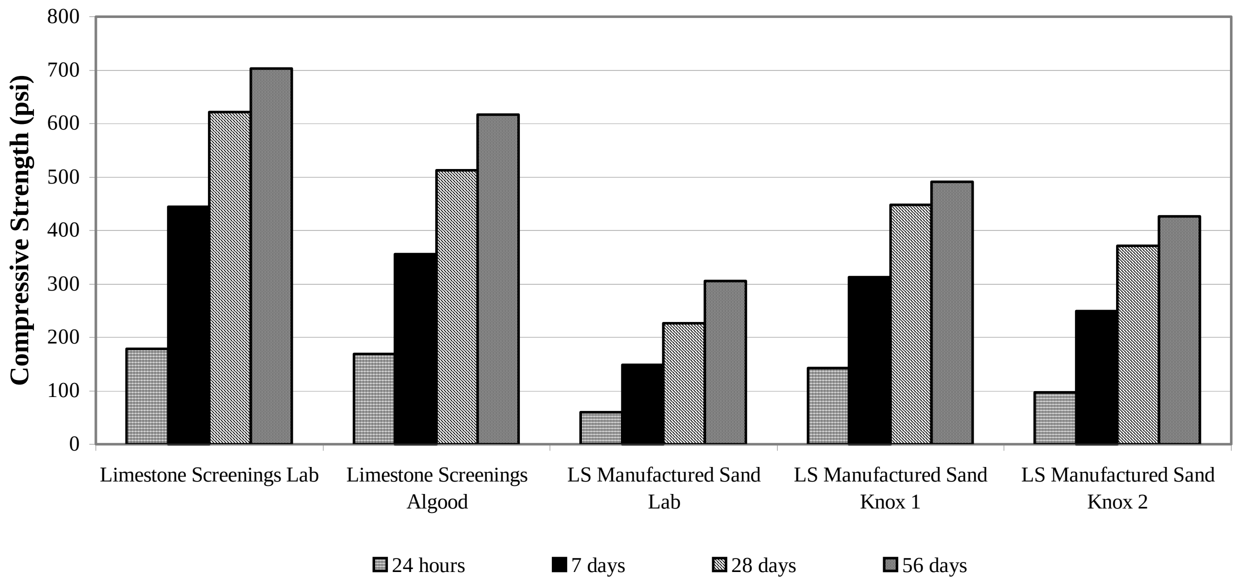

Figure 4. Comparison of Lab and Field Compressive Strength Development for Ohio River Sand Mixtures

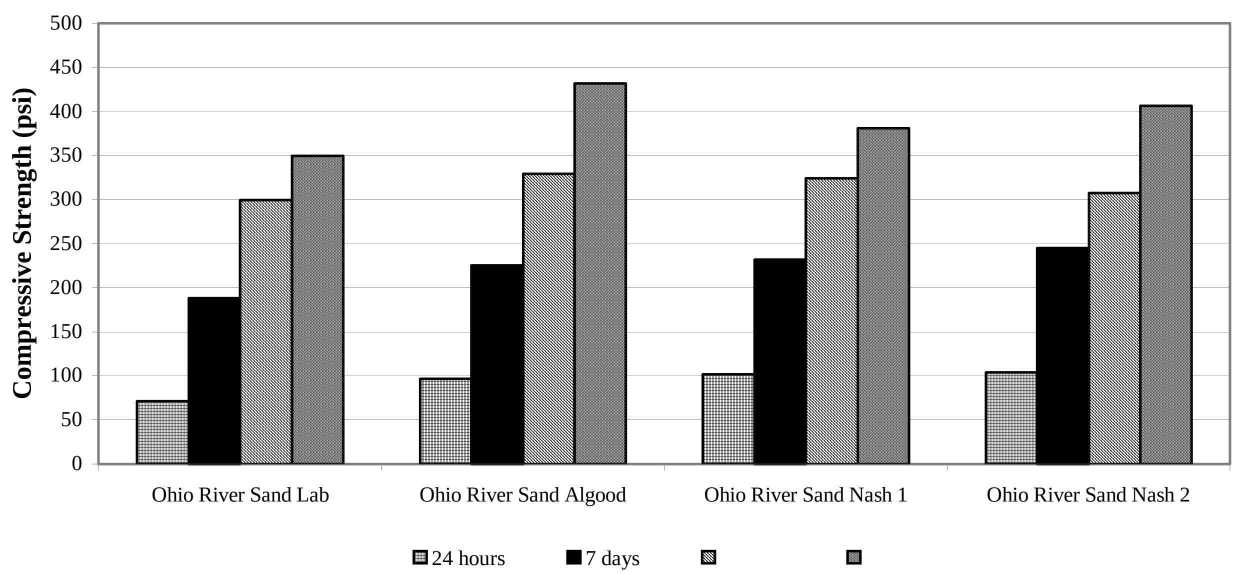

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Figure 5. Comparison of Flow Values

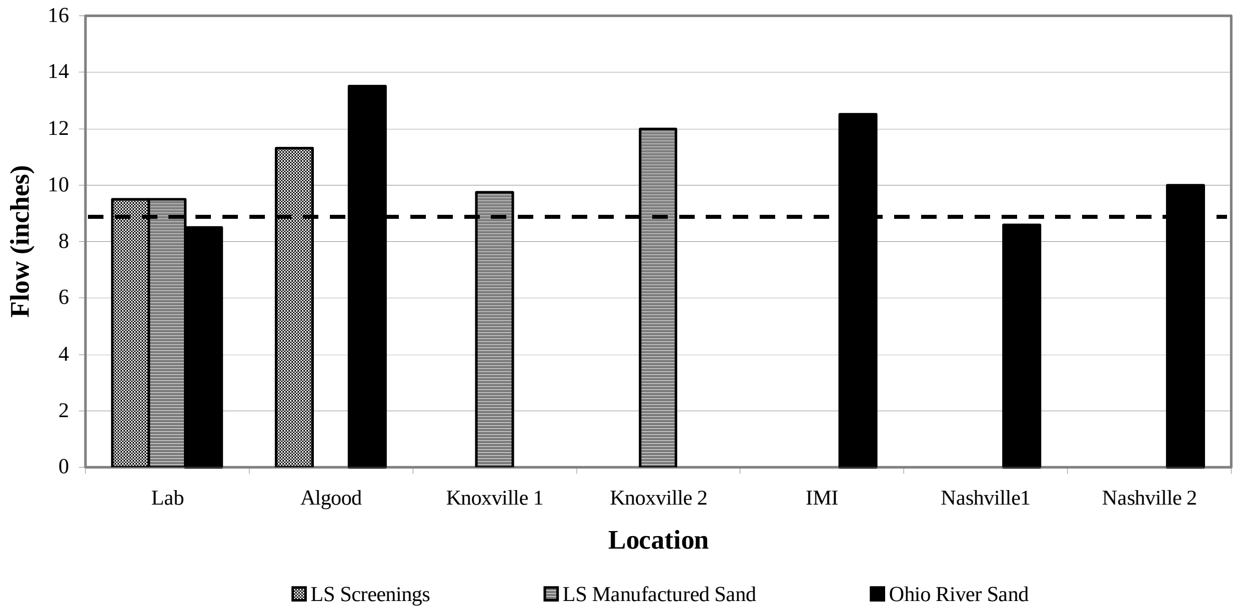

Figure 6. Comparison of Air Contents

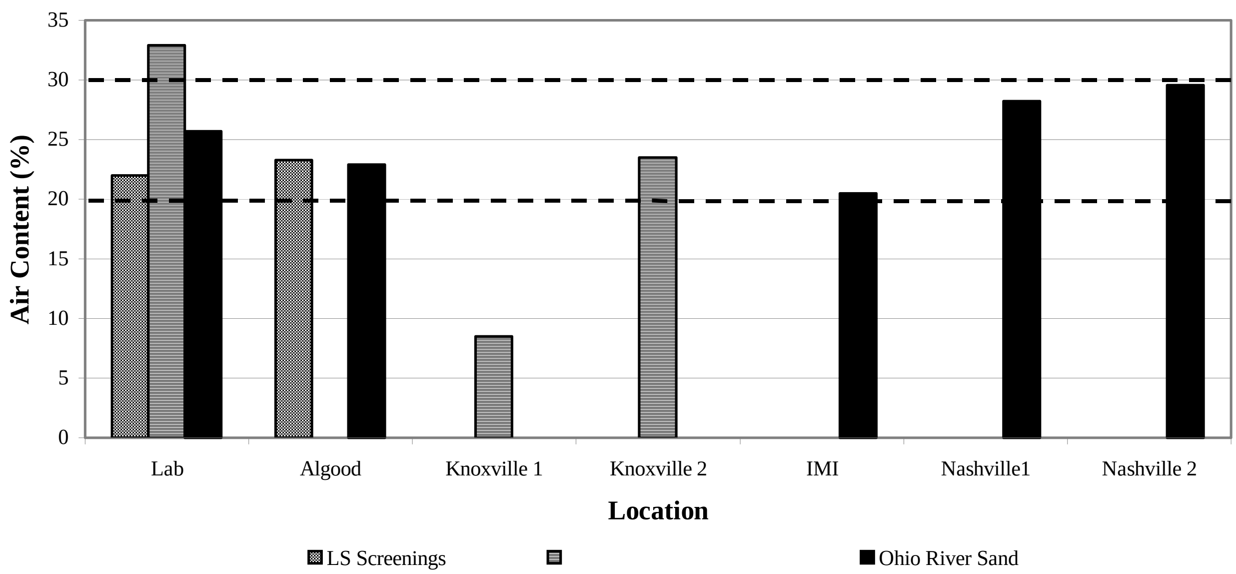

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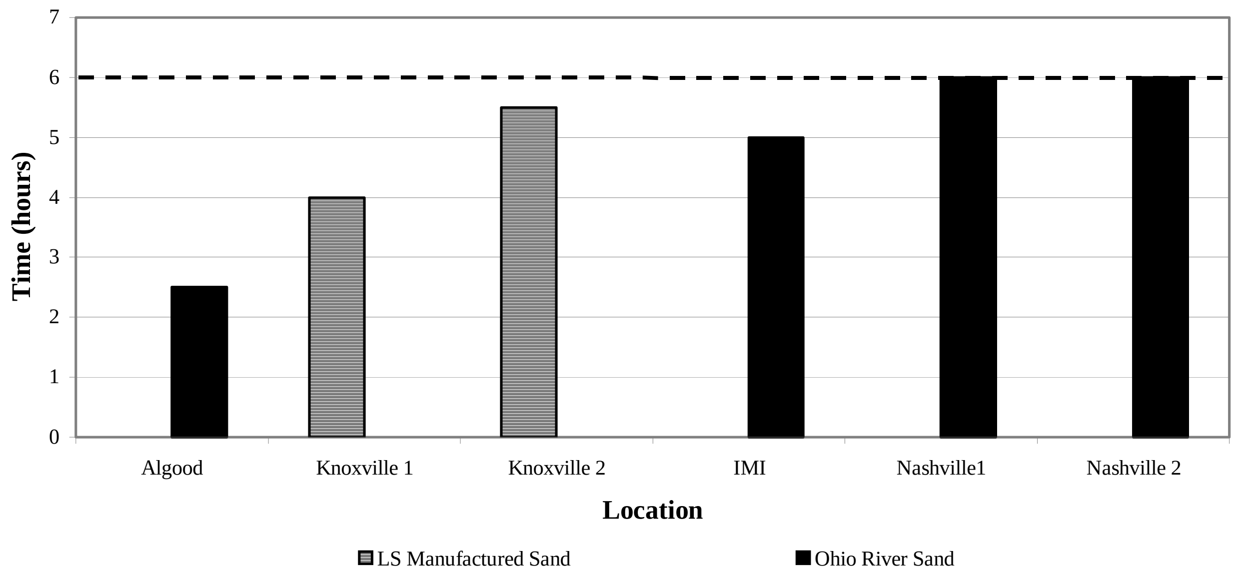
Figure 7. Comparison of Times to Pass ASTM Ball Drop



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